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A Study of Federally Financed Research on Pests, Pesticides and Pest Control

Federal Committee on Pest Control, Washington, D C

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A STUDY OF FEDERALLY FINANCED RESEARCH ON PESTS, PESTICIDES AND PEST CONTROL

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The Federal Committee on Pest Control was established in 1964 by joint agreement among the Secretaries of Defense, the Interior, Agriculture and Health, Education, and Welfare to coordinate all Federal efforts to control pests and to study the effects of pesticides. Subcommittees were established to give special attention to research pesticide monitoring of the environment, public information, review of Federal pest-control programs, and safety in pesticide marketing and disposal.

As one of its functions the Research Subcommittee undertook the task of reviewing all federally funded research in the broad area of interest to determine what aspects most urgently needed strengthening and to reduce undesirable duplication. The summaries and analyses as here presented have been reviewed and concurred in by the parent Federal Committee of Pest Control.

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PREFACE

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A Study of Federally Financed Research on Pests, Pesticides, and Pest Control

INTRODUCTION

In 1965 the Research Subcommittee of the Federal Committee on Pest Control began a project to review Federal expenditures on research to solve the many problems associated with pest control. It was hoped that such an overview would permit an evaluation of the strengths and weaknesses of the current effort and thus enable improvements.

A systematic arrangement to give the best overview of such a complex subject was difficult. Organization by pest or by host organism was discarded because much of the research—especially on mode of application, search for safer more effective pesticides, health hazards, and non-chemical control methods—is independent of pest or host or is so broad that it covers many different pests or hosts. It was therefore decided to outline the problem areas rather than the immediate objectives. The current outline was agreed to after it had been tried out with actual research projects and then modified accordingly. The description of each problem area and subcategory is necessarily brief, but when it is coupled with a summary of current research classified by subcategory, it should give reasonably pragmatic definitions of the scope of each.

Each agency provided figures (see tables) for estimates based on its independent evaluation of each problem area. Everywhere the figures represent the level of annual effort or funding as of the close of fiscal year 1967. Manpower was arbitrarily restricted to research scientists at a GS–11 level or higher, and dollar figures included a pro rata estimate of administrative overhead where such estimates were available. The figures are not uniform; moreover, for those projects in which either manpower or dollars was unknown (as in some extramural efforts), the unknown element was estimated by the arbitrary ratio of $40,000 per 1 scientific man-year. Accordingly, the reader is cautioned against expecting any degree of accuracy in comparing these figures with similar figures from other sources. Where the work has been done by contract with a non-Federal agency, the work is reported under the funding agency. Where the work has been done by a transfer of funds between Federal agencies, it is reported by the agency actually doing the work.

Table 1.—*Federally financed research on pests, pesticides, and pest control*

Problems	Scientific man-years, GS–11 and above	Funding in thousands of dollars
Evaluation of need for control:		
Economics	2.00	80.00
Health	86.10	1,450.70
Comfort and aesthetics		
Other	0.9	36.00
Population dynamics:		
Population dynamics of target organisms	682.15	27,619.52
Interaction between target and non-target organisms	96.71	3,683.30
Population dynamics of nontarget organisms	50.30	2,082.60
Control methods:		
Discovery and synthesis of chemicals including laboratory screening and evaluation	130.25	5,481.30
Field evaluation	224.07	7,438.50
Methods of application	54.35	1,946.30
Mode of action including resistance in target organisms	58.63	3,023.30
Sterilization	68.80	2,455.10
Physiological alteration	15.00	574.00
Cultural control, management practices, and physical protection	117.10	4,533.30
Chemical attractants, repellents and other stimulants	94.00	3,360.60
Integrated control	38.75	1,993.70
Development of resistant host species	275.45	9,172.90
Parasites, predators, and pathogens	115.08	4,749.40
Toxicology, physiology, and behavior of nontarget organisms	144.58	6,412.00
Pesticides kinetics:		
Absorption, distribution, chemical metabolites, accumulation, and excretion	298.70	10,985.15
Methods of speeding residue loss	17.98	679.20
Stability of pesticides in storage	4.15	114.00
Development and standardization of analytical methods	91.00	4,208.60
Marketing, utilization, metrology, and law	13.95	227.40
Totals	3,162.43	98,880.32

Table 1 summarizes all work in each problem area and subcategory by all reporting agencies combined, as of the close of fiscal year 1967.

SUMMARIES AND EVALUATIONS OF CURRENT RESEARCH

EVALUATION OF NEED FOR PEST CONTROL

This area covers research programs designed to evaluate pest, or potential pest, situations from the standpoint of whether there is a need to undertake control programs. Such needs might be classified under economics, health, comfort and aesthetics, or other. Because over 90 percent of the reported research effort is currently classified under health needs, it was decided that this category would be discussed as a unit in this report.

Table 3.—*Federal expenditures for research on evaluation of need for pest control*

Department and agency	Scientific man-years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		1.80		71.00
Agricultural Research Service	1.80		71.00	
Defense		71.30		1,014.00
Interior		2.94		91.75
Bureau of Sport Fisheries and Wildlife	2.25		52.75	
Bureau of Reclamation	0.69		39.00	
Health, Education, and Welfare		13.75		369.90
Public Health Service	13.75		369.90	
Total		89.79		1,546.65

SUMMARY

Investigations in progress are primarily concerned with public health problems and are being conducted by several Federal agencies which include the Departments of Defense, Health, Education, and Welfare, the Interior, and Agriculture. Principal effort is supported by the Department of Defense and is directed toward surveys and studies in strategic overseas areas to determine the presence of zoonotic diseases of military and civilian importance.

Investigative studies focusing on tropical epidemic diseases include both in-house and contract effort and involve basic biological research in epidemiology, serology, immunology, microbiology, parasitology, medical entomology, zoology, virology, rickettsiology, toxicology, and physiology. These studies are designed to develop new and better methods for protection of U.S. military and civilian personnel from the many diseases encountered in worldwide field operations and to study world health conditions in order to estimate the impact of disease on troops sent to foreign areas. Specific studies of military significance under investigation include biology and control of certain Asian helminth disease, ecology and control of the intermediate host of schistosomiasis and other parasitic diseases, arthropod-borne virus diseases, parasitic diseases, field and laboratory ecology of scrub typhus, immunological studies of scrub typhus and its control, parasitic protozoans of medical importance, and vertebrate host in relation to disease of man and other animals. These studies are being conducted in Central and South America, Southeast Asia, the Middle East, and central and east Africa. Nonmilitary-oriented research includes arbovirus (arthropod-borne virus) and host relation of Wisconsin arthropods, studies of chigger mites in western North America, studies on toxicity and carcinogenicity associated with fungal growth on foodstuffs, studies on the toxicity of mycotoxins in certain foodstuffs, and the role of selected stored-product insects in spreading certain potentially dangerous microorganisms and their by-products.

Federal research programs on health problems of pest or pesticide origin seem to be very well coordinated, and no evidence of overlap is apparent.

EVALUATION

Communicable disease still constitutes the major health problems of underdeveloped countries in the world today. Malaria, epidemic typhus, scrub typhus, plague, spotted fever, relapsing fever, hemorrhagic fever, yellow fever, dengue, encephalitis, filariasis, Chagas disease, and visceral and cutaneous leishmaniasis represent some of the major diseases transmitted by arthropod pests for which effective methods of control are being studied. Schistosomiasis, paragonimiasis, clonorchiasis, and fascioliopsiasis, although not arthropod-borne, are also major diseases in various geographical areas of the world where similar control attempts are being directed toward the intermediate snail host as well as developing means of immunological protection for the human host.

Control of vectors of disease is a serious problem because of pesticide resistance or altered behavioral response. For example, the resistance of the malaria parasite, *Plasmodium falciparum*, to chloroquine has created a very serious problem in the prevention of falciparum malaria. These resistance problems are so widespread geographically that a common solution to the problem has not been possible.

A major portion of research is being accomplished outside the continental United States, and this fact creates a variety of problems—great distances need to be traveled by U.S. investigators; capable, trained in-country professional and technical personnel are not available; more research facilities are needed; transportation is unreliable; and interest or support by local government is lacking.

Availability of funds to support this kind of research has been rather modest, but reasonable progress has been made. However, before any major success can be forthcoming it will be necessary to put increased effort into the

present programs. The sentences of the present dollar drain could have serious effects on the current program. The war in Vietnam could also influence the direction of research undertaken. Immediate solution to these disease problems cannot be expected.

Losses in yields and quality of food, feed, and fiber crops due to insects, weeds, disease organisms, nematodes, and rodents — either individually or in association — need to be determined. Such information will provide the bases for establishing priorities in research and control programs with attendant increased efficiency in expenditures for pest control. Research of this nature is essentially nil currently and represents a serious gap.

POPULATION DYNAMICS

POPULATION DYNAMICS OF TARGET ORGANISMS

Programs are designed to study the biology, ecology, life history, physiology, morphology, taxonomy, nutrition, metabolism, habits, and behavior of target organisms. When these same subjects are studied as part of the control measures, they are classified under "Control Methods."

Table 3. — *Federal expenditure for research on population dynamics*

Subcategory	Scientific man-years GS–11 and above	Funding, in thousands of dollars
Target organisms	882.15	27,639.52
Interaction between target and nontarget organisms	96.71	3,483.30
Nontarget organisms	59.20	2,082.60
Total	1,038.06	33,305.42

Table 4. — *Federal expenditures for research on population dynamics of target organisms*[1]

Department and agency	Scientific man-years GS–11 and above		Funding, in thousands of dollars	
Defense		140.50		665.00
Interior		5.13		164.00
Bureau of Reclamation	0.23		8.00	
Bureau Sport Fisheries and Wildlife	4.90		156.00	
Agriculture		888.84		25,012.30
Forest Service	94.00		3,290.00	
Cooperative State Research Service	97.84		2,826.00	
Agricultural Research Service	497.00		16,896.30	
Health, Education, and Welfare		75.00		2,943.52
Public Health Service	75.00		2,943.52	
National Science Foundation		53.60		2,145.00
Atomic Energy Commission		15.50		191.00
Tennessee Valley Authority		0.50		12.00
Total		978.86		31,132.82

[1] Combined with interaction between target and nontarget organisms (Table 5).

Summary

The broad study of population dynamics of pest organisms includes research on life histories, ecological relationships, and population fluctuations as they pertain to development and application of pest-control measures. It includes interactions between target organisms and all factors of their environments, including nontarget organisms. Relative to pest control it also includes taxonomy, nutrition, physiology, and behavior.

The objectives of this line of work are, simply stated, to explain what different kinds of pest species and populations do and how they do it. Each pest species behaves differently and interacts differently with all facets of its environment. Basic information on these factors is requisite for devising and implementing any kind of pest-control approach, from the simplest mechanical device to the most elaborate scheme of integrated control. Researchers must understand the pest and how it operates in every instance. The more sophisticated the approach to control, the more thoroughly the pest must be understood.

Work is underway on a wide array of subjects. These include invertebrates directly affecting man and animals, crops, forests, and stored products and material in use, such as wood and fabric. Vertebrate pests such as rats and other rodents are being studied, as are nuisance and destructive birds — for example, starlings and blackbirds that feed on crops and herring gulls that often menace aircraft. Major efforts are in the study of weeds, nematodes, and plant diseases. Arthropod vectors of diseases of man, plants, and animals constitute a large field of study.

Evaluation

An adequate research effort in this subject area is underway in only a few limited fields; much more needs to be done. This is particularly true in ecology of pest organisms and is increasingly important as pest control problems become more complex. We are still faced with many of the old pest problems, and many considered solved once are returning again — for example, resistance of some insects to certain modern insecticides has become a major obstacle. In this regard there is not even any assurance that some of the more exotic approaches looked to for the future, like utilization of hormones to disrupt life processes, will not also be followed by similar adaptation of pest populations to the new factor. Furthermore, the expanding human population and increasing concern for the quality of the environment are additional complicating factors that bear on the need for a better understanding of how pests operate.

It seems from agency responses that lines of study considered most important are receiving at least some attention at the Federal level. Those considered less important, other things being equal, are sometimes being neglected. This is the inevitable result of limited financing and necessitates strict economic and other evaluations in the selection of problems for study.

A great number of important studies are not being undertaken. Apropos of this, one agency representative indicated that while considerable time and money have been devoted to the trial-and-error method of testing pesticides for use against various arthropods, relatively little effort has been expended in conducting studies on the arthropod itself. The reasons for this aspect probably lie in the lack of appreciation for complexity of the problem by higher administrative levels and the fact that such work requires long periods of investigation in which results are slow in forthcoming so far as their application to the practical field problem. Furthermore, where funds are limited, the work that has been done has been directed along the applied lines to support program needs.

It would seem that a different kind of research climate needs to be encouraged so that more attention is given to achieving optimum gains in the long run. It is often difficult to retain support for long-term studies when there is excessive pressure for quick answers.

POPULATION DYNAMICS OF NONTARGET ORGANISMS

Studies are being conducted on the effects of pesticides on field populations, including measurement of immediate mortality, long-term effects on reproduction and survival, and effects on species composition density. Studies on pests, or potential pests, which are not the primary target are included here, as are epidemiological studies.

Summary

The objectives of this research are to determine what happens to nontarget organisms that encountered pesticides. These organisms include man himself, other mammals, wild birds, plants, fish, and beneficial insects, including parasites and predators as well as honeybees and other pollinating insects.

Examples of research being carried out include a community study program that seeks to determine the long-term effects of pesticides on humans. Selected populations are surveyed at intervals in an effort to detect disease that can be related to pesticide contact.

Studies are being made of the response to insect parasites and predators to insecticides in efforts to identify insecticides providing maximum insect-control benefits and minimum adverse effects on the ecosystem. Studies on wildlife concentrate on determining if pesticides in the environment are exerting deleterious effects as demonstrated by declines in numbers, reduction in reproductive success, or changes in habits or behavior. Both long-term studies as well as those pertaining to specific pest-control efforts are being conducted. Some research is conducted to determine ecological shifts in plant communities following extensive use of herbicides.

Evaluation

It is generally recognized that pesticides can affect many elements of an ecosystem in addition to the target pest. This has been amply demonstrated, yet research on these effects lags far behind that on population dynamics of the target organisms themselves. Increased emphasis is needed in many phases, including (1) evaluating effects of pesticides on beneficial insects, (2) biological and ecological studies on beneficial insects, particularly parasites and predators, (3) short- and long-range effects of pesticides on fish, wildlife, and plant communities, (4) continuing observation on human populations known to be exposed most heavily and over a longer period of time, and (5) the ecological effects of extensive and repeated use of herbicides to kill or defoliate herbaceous and woody plants.

Support for long-term studies in this area is often hard to get, and the studies themselves are costly and difficult to carry out. Sometimes operational programs shift emphasis and move away from earlier problems; this makes long-term studies less attractive to undertake. There has long been a tendency for a minimum direct contact and attempts at mutual understanding between groups interested in target and nontarget organisms. Understanding is improving, but much yet remains to be done. Much of the research in this area has been done on the chlorinated hydrocarbon pesticides, and there is need to continually review the overall research effort to determine if current work on pesticides is being correlated with changing pesticide-use patterns.

Table 5. *Federal expenditures for research on population dynamics of nontarget organisms*

Department and agency	Scientific man-years, GS–11 and above		Funding, in thousands of dollars	
Interior		15.35		883.90
Bureau of Sport Fisheries and Wildlife	10.75		278.30	
Bureau of Commercial Fisheries	3.60		104.60	
Agriculture		5.10		145.90
Agricultural Research Service	5.10		145.90	
Health, Education, and Welfare		33.85		1,359.80
Public Health Service	33.85		1,359.80	
National Science Foundation		4.90		194.00
Total		59.20		2,583.60

CONTROL METHODS AND EVALUATION

All research programs on the development and evaluation of pest-control procedures are classified in this problem area, as are long- and short-term population effects of control measures on target species as well as other physiological, economic, and ecological studies related to control. Economic studies that measure the cost of a particular control operation in relation to its effectiveness, as compared with costs of other methods, are included. Economic studies of losses inflicted by pests are under "Evaluation of need for pest control."

DISCOVERY AND SYNTHESIS OF CHEMICALS INCLUDING LABORATORY SCREENING AND EVALUATION

Summary

Primary research emphasis within this subject area relates to agricultural-type insects (including mites and ticks); various pest fish and animal species; forest insect and disease pests; weeds; fungi and other forms of unwanted vegetation; and insects, rodents and certain invertebrate parasites of human health significance, arranged in decreasing order of emphasis. Research related to nontarget organisms includes use of ^{14}C-labeled piperonyl butoxide to determine synergist kinetics in the nontarget host; studies on pathogenesis, epidemiology and control of filariasis; and the investigation of new drugs and antigens and chemical factors in host plant selection by insects.

The major effort is in the discovery, identification, synthesis, and screening of new insecticides and repellents, but with particular emphasis on attractants, sterilants, and stimulants that control insect (mite and tick) populations. Compounds utilized in this effort are derived from U.S. Department of Agriculture laboratory and industry synthesis. Toxicants, repellents, attractants, surfactants, and stupefacients for rats, birds, fish, and some other animals; attractants, repellents, and chemosterilants for a small amount of research on nematode control; and various poisons, repellents, and chemosterilants for the control of undesirable fish and parasitic organisms are largely obtained from industry for evaluation against test plant and animal forms. It should be noted that from whatever the source, only a small fraction of the numerous compounds discovered and screened shows biological activity warranting subsequent laboratory and field development.

The objective of the above described work is the development of new chemical compounds that will not only be effective for the control of pests but will obviate problems associated with pesticide resistance, residues in food, and residues deleterious to nontarget organisms in the environment.

Evaluation

The development of new and safer herbicides, insecticides, nematocides, and fungicides is limited by the lack of basic research to determine structural activity relationships, mode of action, and specialized techniques for evaluating chemicals. From a broader standpoint, there is need for a number of small-use (but important) pesticides that is not being met by industry owing to limited sales potential. Federal funds for such research are low in view of the need. Examples include irrigation system weeds, rodent toxicants and repellents, bird and fish control agents, and selected animal chemosterilants. Under current regulations, companies cannot enjoy exclusive benefits from patents on materials discovered by federally supported research, even though they would produce the product. There is also the attitude that since industry profits from development, industry should be the primary source of new compounds.

Table 6.—*Federal expenditures for research on control methods and evaluation*

Subcategory	Scientific man-years, GS-11 and above	Funding, in thousands of dollars
Discovery and synthesis of chemicals including laboratory screening and evaluation	130.23	5,463.30
Field evaluation	226.07	7,448.50
Methods of application	84.25	1,936.30
Mode of action including resistance in target organisms	58.65	3,013.80
Sterilization	64.80	3,455.10
Physiological alteration	15.00	574.00
Cultural control, management practices, and physical protection	117.15	4,433.30
Chemical attractants, repellants, and other stimulants	74.05	3,150.60
Integrated control	34.72	1,993.70
Development of resistant host species	275.45	9,172.90
Parasites, predators, and pathogens	117.68	4,749.40
Total	1,163.07	42,510.30

Table 7.—*Federal expenditures for research on discovery and synthesis of chemicals including laboratory screening and evaluation*

Department and agency	Scientific man-years, GS-11 and above		Funding, in thousands of dollars	
Agriculture		100.77		4,329.80
Agricultural Research Service	88.70		3,910.10	
Forest Service	10.00		346.00	
Cooperative State Research Service	2.07		65.70	
Health, Education, and Welfare		11.35		417.80
Public Health Service	11.35		417.80	
Interior		13.41		903.70
Bureau of Commercial Fisheries	1.37		62.10	
Bureau of Reclamation	1.96		50.90	
Bureau of Sport Fisheries and Wildlife	9.18		391.70	
National Science Foundation		6.80		333.00
Total		130.23		5,463.30

Research on new fumigants and space spray compounds, particularly on compounds for quarantine treatments of agricultural products moving in commercial carriers interstate and from overseas, does not appear commensurate with actual and potential pest control problems. Research

on nematicides also seems to be at a low level of effort in view of the increasing recognition of the role of nematodes in crop yield reduction.

Identified among high priority research needs is the development of special-use pesticides for certain crops and weeds, plant disease organisms, vertebrates, insects and other invertebrates that will not harm nontarget organisms, lead to harmful residues in food, feed, and fiber, or pollute components of the environment. It is recommended that research capabilities be increased to allow evaluation of new and unusual compounds in greater depth.

FIELD EVALUATION

Summary

Field evaluation research is being conducted in several Federal agencies, notably in the Departments of Agriculture, the Interior, and Health, Education, and Welfare. In addition, there are over 160 federally supported projects in the 53 State Agricultural Experiment Stations. The bulk of research is in:

(1) Evaluation of insecticides and acaricides for control of insect and mite pests on crops in nine broad commodity areas and on insect and invertebrate pests or disease vectors in man and livestock.

(2) Evaluation of herbicides and nematocides for control of about 100 of 18000 important weeds and 15 of the 100 nematodes most damaging to crops in these commodity areas.

(3) Evaluation of fungicides for control of rusts, smuts, root rots, and as seed protectants.

Table 8. — *Federal expenditures for research on field evaluation*

Department and agency	Scientific man years (GS–11 and above)		Funding, in thousands of dollars	
Agriculture		186.74		6,130.50
Agricultural Research Service	126.60		4,521.10	
Cooperative State Research Service	60.14		1,609.40	
Defense		1.80		77.00
Health, Education and Welfare		13.10		330.60
Public Health Service	1.10		330.60	
Interior		11.53		413.40
Bureau of Reclamation	0.53		18.30	
Bureau of Sport Fisheries and Wildlife	11.00		395.10	
State		9.00		478.00
Tennessee Valley Authority		.80		19.00
Total		234.97		7,438.50

(4) Evaluation of pesticides, repellents, attractants, antifertility agents, baits, and frightening devices for control of birds, rodents, and other mammals which damage crops, livestock, wildlife, and electrical and other installations.

In addition, plant-growth regulators are evaluated for effectiveness in promoting seed germination, as chemical pruning agents, and as growth promoters and retardants in selected crops. Chemicals are being studied for effectiveness in controlling undesirable aquatic organisms such as weeds, trash fish, and mollusks. The effects of insecticides on target insects, rodents, and cohabitating nontarget organisms are being tested in the *Aedes aegypti* Eradication Programs. Field evaluation programs include study of many factors influencing successful pest control, among which are the following: (1) overall effectiveness of the compounds including the influence of formulation, timing, rate, and method of application and total dosage, (2) specificity for target organisms, (3) safety and economy of use, (4) effects of yield and quality of crop commodities and animal products, (5) persistence in the environment, (6) interaction and compatibility with other practices leading to integrated systems of control and employing techniques which combine biological and physical management with use of chemicals, and (7) ancillary studies of the ecological effects of pesticide use on target and nontarget organisms. The relative emphasis on the above factors varies somewhat depending on the pest and control method being evaluated.

A small extramural research program encompassing several major aspects of vector control including bionomics and ecology of insects endemic to Asia, studies of trematodes, and insect vector control compliments intramural investigations.

Evaluation

There is an urgent need to expand present research to include evaluation of control methods for weeds, nematodes, insects, and disease organisms not now studied and to improve control techniques for lower value and minor crops where emphasis has been lacking. The potential utility of growth regulators to increase yield without impairing quality needs to be explored, especially in vegetable, tobacco, and sugar crops. New developments in control techniques should be rapidly exploited to offset the development of pesticide resistance in insects and the withdrawal of persistent insecticides from the market. The number, effectiveness, and safety of pesticides need to be improved for use on commodities regulated by plant quarantine, for use on stored processed foods awaiting consumer use and for use as systemic fungicides. More detailed information is necessary on problem pests themselves and on the environments which produce them. In some situations there can be a significant gap between developmental evaluation research and final operational use which should be corrected. Evaluation of new control techniques, including the use of chemicals, has to be integrated with existing methods of control and with control devices concurrently employed on other pests to provide

a total control system appropriate to a given situation. Research of this type would include an assessment of the ecological implications of total control systems and the long-term effects of pesticide use on target and associated nontarget biota. Such investigations will require improved interdisciplinary coordination employing the combined efforts of scientists in entomology, wildlife management, weed science, nematology, crop husbandry, pathology, ecology, engineering, chemistry, and plant, animal, and insect breeding. Evaluation research for pest control in the aquatic environment offers a striking opportunity to employ interdisciplinary talent in developing safer and more effective methods of field use.

METHODS OF APPLICATION

Summary

Research covers application of pesticides in general, such as insecticides, herbicides, nematocides, fungicides, and acaracides.

Current research efforts are directed to the development of fundamental information about the physical characteristics of pesticides, target-placement mechanisms, needed equipment, and techniques for improving the efficiency of pesticide application. Research being carried out for a specific purpose ranges from the most fundamental type on the physics of forces affecting fine particles to development of a better "coyote getter." Some research is general in nature, with wide applicability while other is for a limited and specific purpose.

The larger part of the research is directed to the problems of agriculture and food production with most emphasis being placed on crops and animals of the largest economic significance. Approximately one-fourth of the total effort is related to the production of major field crops and about one-fifth to forest production.

Some research is directed toward developing principles and new methods of application. Pesticides are [illegible]

Table 9.—*Federal expenditures for research on methods of application*

Department and agency	Scientific man-years (GS–11 and above)		Funding, in thousands of dollars	
Agriculture		47.30		1,712.30
Agricultural Research Service	32.30		1,211.30	
Cooperative State Research Service	4.00		136.00	
Forest Service	11.00		365.00	
Defense		1.80		10.00
Health, Education, and Welfare		4.40		165.60
Public Health Service	4.40		165.60	
Interior		0.75		33.30
Bureau of Sport Fisheries and Wildlife	0.75		33.30	
Total		54.25		1,941.30

liquids, pastes, foams, granules, and other absorbed formulations; they include foliar, soil surface, subsurface, and directional treatments which increase effectiveness, improve precision placement, and reduce dosage and pollution effects. Improvement of techniques for applying herbicides to ditchbanks and in aquatic environments such as canals, reservoirs, and irrigation ditches is being investigated to a limited extent in the South and West. Methods of applying herbicides by aircraft and ground-level powered machinery are being studied for control of weeds in nontilled crops and grazing lands and for the long-range management of range lands for agricultural use.

Projects on ultra low volume application are of interest in several departments—all having as their objective equal or better control with less total pesticide usage and a consequent reduction in pesticide residues and environmental pollution. To accomplish this objective, research is directed toward a better understanding of particle formation and particle movement control as well as the development of practical equipment and techniques to gain this control.

Evaluation

Much progress has been made in the past few years in methods of applying pesticides. Developments have, in general, been of a more applied nature, and it is the judgment of many researchers that the technology of pesticide application has now reached a plateau. Future progress along conventional lines will be slow, and new breakthroughs in efficiency of application will depend upon the development of a better understanding of fine-particle physics as it relates to the formation of particles and their control and placement on the target organism in the desired manner. Also the development of new materials as, for example, systemic insecticides will require research to develop specialized methods and equipment for most effective use.

The pollution of air and water, including that caused by pesticides, is a matter for concern. The drift of fine particles is undesirable, and new ways of controlling particle size and placement are needed.

More effective methods of applying herbicides, fungicides, and nematocides are needed to reduce application costs, lower dosages, reduce operation costs, and avoid harmful residues in soil, water, and air. Cooperation of agricultural engineers with pest-control specialists of other disciplines is needed to evaluate fully and develop new equipment to meet requirements for applying pesticides to rangelands, annual cultivated crops, perennial crops such as fruit trees and in nurseries, and for control of weeds in aquatic environments. Multiple-use application techniques and equipment are required for practical integrated control of weeds, nematodes, fungi, and insects.

Research in methods of application is paralleling, and properly so, research in nonchemical biological methods. In fact, success in some of the biological methods will depend on methods of applying biological materials. Research on application will complement that on biological controls.

A review of present research in this area indicates that a reasonably well-rounded program is underway. However, greater efforts will be needed to meet increasing needs.

MODE OF ACTION INCLUDING RESISTANCE IN TARGET ORGANISMS

Summary

The intensity of biochemical and physiological research on mechanisms of pesticide intoxication or detoxification and resistance varies widely according to target organisms or the use areas: insecticides, miticides, herbicides, fungicides, piscicides, molluscicides, avicides, rodenticides, and other pesticides. The greatest effort (about 78 percent) is focused on entomological problems; most of this is on mechanisms of detoxification and resistance in flies, mosquitoes, boll weevils, bollworms, corn earworms, German cockroach, greenhouse mites, and other arthropods to organochlorine, organophosphorus, and carbamate pesticides. Less effort is on mechanisms of degradation, fate or storage of pesticides, and biochemistry of resistance. About 13 percent of effort is devoted to mechanisms of action and related studies in herbicides and fungicides involving pesticide degradation; nucleic acid synthesis; enzymes in metabolism; mutagenicity in a model system; and protective, synergistic, or modifying effects of multiple exposures. A small portion of the research effort (2.5 percent) is designed to elucidate biochemical and physiological mechanisms and differences in metabolism and acid-base balance of selected tissues and renal function in different species of fishes, birds, and mammals.

Evaluation

Efforts in this subcategory are hindered by a lack of public interest and support for the elaborate analytical instrumentation required; on the other hand, efforts are encouraged by general concern for developing highly selective pesticides without effect on nontarget organisms. Areas of entomological research vary according to species and circumstances of pesticide usage, for example, applications to pests in the field as opposed to pests in stored products. Exploration of differences in physiological and biochemical mechanisms between target and nontarget organisms will establish guidelines for the development of new and more specific pest-control agents with greater safety and less hazard to nontarget organisms.

Much more research information is needed to guide synthesis and application of more effective agents against (1) resistant strains of various arthropod vectors of public health importance, (2) insects, disease organisms, nematodes, and weeds involved in plant protection, (3) nuisance animal populations, and (4) pests without harmful side-effects on nontarget organisms.

Table 10.—*Federal expenditures for research on mode of action including resistance in target organisms*

Department and agency	Scientific man years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		33.77		1,351.40
Agricultural Research Service	27.80		1,137.00	
Cooperative State Research Service	5.97		214.40	
Defense		3.00		70.00
Health, Education, and Welfare		15.83		555.80
Public Health Service	15.83		555.80	
Interior		1.70		33.00
Bureau of Sport Fisheries and Wildlife	1.70		33.00	
Atomic Energy Commission		4.00		91.00
National Science Foundation		.50		11.00
Total		58.62		2,051.20

STERILIZATION

Summary

Sterilization of insects by radiation, chemicals, or adverse genetic effects employs the insects to suppress or eliminate the normal reproduction of the entire population. Research on sterility for insect control involves two different approaches. One method involves the mass rearing, sterilization, and release of insects to compete for mates with insects in the natural population. The other involves chemosterilants in lieu of insecticides to control reproduction of insects in the natural population. The work also involves research on sterility to suppress reproduction in vertebrate pests.

Research is under way to determine application rates of gamma radiation or chemicals that will cause sterility in insects without otherwise affecting their normal activities.

Table 11.—*Federal expenditures for research on sterilization*

Department and agency	Scientific man years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		66.60		1,972.70
Agricultural Research Service	34.20		1,011.50	
Cooperative State Research Service	6.40		21.20	
Forest Service	4.00		140.00	
Defense		6.90		99.00
Health, Education, and Welfare		3.6		13.20
Public Health Service	0.16		13.20	
Interior		2.00		70.20
Bureau of Sport Fisheries and Wildlife	2.00		70.20	
Atomic Energy Commission		9.00		180.00
Total		84.86		2,455.10

Laboratories in different parts of the country are studying initial and delayed effects of varying rates of radiation against such pests as codling moth, subtropical fruit flies, house flies, mosquitoes, corn earworm, boll weevil, pink bollworm, tobacco hornworm, tobacco budworm, cabbage looper, cereal leaf beetle, and plum curculio. Promising results obtained with gamma radiation of the codling moth and several fruit fly pests have led to large-scale field evaluations of releasing sterilized insects for control of these pests. Plans are under way to conduct pilot tests to evaluate the effectiveness of released sterile insects for suppressing populations of the codling moth, pink bollworm, boll weevil, tobacco budworm, corn earworm, and *Drosophila* fruit flies.

In order to find better and safer chemosterilants to sterilize insects for release or for use against natural insect populations, over a thousand chemicals were screened against the house fly, 159 against the screw-worm, and 300 against the boll weevil within a year's time. Laboratory tests are under way to evaluate tepa as a sterilant against the oriental fruit fly, melon fly, Mediterranean fruit fly, pear psylla, Mexican fruit fly, European corn borer, fall armyworm, false wireworm, and Japanese beetle; apholate against the cereal leaf beetle and several species of mosquitoes; and metepa against mosquitoes. Different rates of application are used, and various ratios of sterilized to untreated insects are used to determine the degree of sterility and side effects to the insects. Investigations are under way to determine the best ways of administering the chemosterilants; because these materials are hazardous, care is taken to determine the time it takes for them to break down into harmless materials.

Studies are under way on the embryological action of candidate chemosterilants, especially Sudan Black, on birds. In the laboratory, oral doses are given to caged common *Sturnus*; in the field, Sudan Black is mixed with bait and placed on selected islands along the New England coast where herring and great black-backed gulls breed.

Evaluation

The President's Science Advisory Committee and other fact-finding committees have pointed out the need for methods other than conventional pesticides to control insects and other pests. Great concern has been expressed on the widespread and heavy use of insecticides and the resultant problems of insects becoming resistant to insecticides and the side effects of residues in connection with food and feed crops, soil contamination, adverse effects on fish, wildlife, and beneficial insects, and pollution of the environment. Great hope has been expressed in the development of biological and genetic approaches to pest control. The successful sterilization of screw-worms and subtropical fruit flies without any or only minimal damage to these insects has made it possible to make sustained releases of sterile insects over sizeable areas for the control or eradication of these pests. Unfortunately, some species of insects cannot be sterilized without physiological damage. This is particularly true for the boll weevil. Much research remains to be done to evaluate the direct effects of radiation on different insects of economic importance to agriculture, forestry, wildlife, and man. The use of insects sterilized by radiation for control of pest species is a highly selective procedure, and wherever it can be used there is assurance of no ill effects of residues. The method has greatest applicability to the treatment of isolated or rather circumscribed areas of infestation. Needed research includes techniques for rearing of millions of insects, methods of irradiation, determination of effective ratio of treated to untreated insects, and methods of releasing sterilized insects. The bridging of the gap between sizeable experimental plots and practical large-scale operations to determine efficacy of the method against a particular pest is very costly. Such a program is not of immediate interest to private industry. Therefore, basic research on sterility methods, nutritional requirements of insects and applied research involving mass rearing of insects, and field demonstrations on a large-scale basis will have to be undertaken by public-supported agencies.

Research on chemosterilants to find ways to sterilize insects in the natural population needs to be increased. Safer materials must be found or selective ways to use them in highly selective baits or other attractants have to be developed. Promising materials or methods need to be evaluated against pest insects, birds, and mammals. Ways must be found to utilize these chemicals to sterilize the pests and thus reduce their ability to compete with the untreated animals. Methods of analyses and bioassays must be developed for the original compounds and their breakdown products to insure that no harmful effects will result.

The development and release of strains of insects with cytoplasmic incompatibility is a new genetic approach to sterility that merits substantial support. Based on practical results to date, the research effort on the use of released sterile insects for population suppression should be greatly expanded. Research on incompatible cytoplasmic insect strains should be initiated as soon as possible to develop this genetic approach to sterility. Research on chemosterilants for use to control reproduction in natural pest populations should be increased considerably.

PHYSIOLOGICAL ALTERATION

Summary

Entomological research on physiological alterations that might contribute to control of insects is concentrated on physiology and juvenile hormone activity in relation to insect metamorphosis. Chemosterilants, antimetabolites, antifeedant agents, and other chemicals or natural substances that may alter biochemical processes which involve stress effects on insect physiology (disease vectors) and genetic studies on snail vectors of schistosomiasis are also being studied. Research on fish and wildlife deals primarily with enzymes, coenzymes, cofactors (vitamins, minerals, and hormones) and genetic aspects involving the pharmacological interaction of pesticides. These biochemical and chemical and physiological measurements provide guidelines for

Table 12.—*Federal expenditures for research on physiological effects of pests*

Department and agency	Scientific man years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		10.59		195.10
Agricultural Research Service	8.40		172.10	
Cooperative State Research Service	1.99		23.00	
Health, Education, and Welfare		3.65		151.80
Public Health Service	3.65		151.80	
Interior		1.05		24.10
Bureau of Reclamation	0.30		10.60	
Bureau of Sport Fisheries and Wildlife	.75		13.50	
Total		15.09		374.00

assessing hazards or benefits of agents useful in controlling fish, bird, or mammal populations. A small effort is devoted to weed control, particularly to induce or break dormancy and stimulate germination of seeds or cysts of plant-feeding nematodes during unfavorable weather or to reduce time spent for ease in control.

Evaluation

This research is relatively new and highly complex and involves considerable difficulty in development of suitable experimental methods. Although progress is necessarily slow because of the basic and exploratory nature of these investigations, the recent breakthroughs in identifying and synthesizing potent hormones from insects and plants has shown promise. Further physiological studies on endocrinology, enzymology, and pharmacology in target organisms is urgently needed to provide fundamental criteria for guiding research in isolating, identifying, and synthesizing natural materials for control of insects, weeds, fish, birds, and mammals. Accordingly, increased support is necessary for this highly technical research to explore new and highly selective avenues of control other than use of chemical toxicants.

CULTURAL CONTROL, MANAGEMENT PRACTICES, AND PHYSICAL PROTECTION

Summary

Current research includes fundamental studies on ecological relationships of insects, plants, birds, and diseases. Other basic studies are being conducted on the relationship of plant physiology to fungal infection and the factors affecting biological behavior of mosquito disease vectors to name some examples. Research ranges from basic—response of target organisms to ecological changes effected through cultural or management practices—to more practical—the development of coarse devices for protecting crops from depredating birds. Some of the research is general in nature with wide applicability while other is for limited and specific purposes. The development of cultural practices to control insects is being investigated in order to overcome problems associated with the extensive use of insecticides, for example, insect resistance and residue problems. Studies are also underway to determine the utility of electromagnetic radiation for detection and control of insect pests.

The larger part of the research is directed to the problems of agriculture and food-crop production. For example, research to develop physical and cultural methods for control of plant diseases, nematodes, and weeds constitutes about one-third the total effort in this area.

Several projects on ecology management are carried on in a number of agencies. Insect biology is being intensely studied so that the use of pesticides can be reduced.

Other areas of research are concerned with protection of military personnel, with protection of forested areas, and with the protection and preservation of food products as they move through the market place.

Evaluation

The breadth of research covered in this area is such that projects are widely diversified both as to content and between departments. This diversity is not objectionable since it serves the needs of the departments and of the geographic areas concerned.

Efforts to make more use of cultural and mechanical control methods need to be increased and coordinated with pesticide practices to achieve greater efficiency of crop production. These approaches eventually will lead to reduced need of pesticides and will provide better control on crops where pesticides cannot be used because of prohibitive costs, residues, or phytotoxicity.

Table 13.—*Federal expenditures for research on cultural control, management practices, and physical protection*

Department and agency	Scientific man years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		98.80		3,967.60
Agricultural Research Service	84.40		3,448.60	
Cooperative State Research Service	6.40		139.00	
Forest Service	8.00		380.00	
Defense		1.00		19.00
Health, Education, and Welfare		1.00		13.00
Public Health Service	1.00		13.00	
Interior		3.65		64.90
Bureau of Sport Fisheries and Wildlife	3.00		38.00	
Bureau of Reclamation	.65		26.90	
Tennessee Valley Authority		0.70		17.30
Total		117.15		4,121.80

Fundamental information useful in nonchemical control is being gathered, as for example the information on specific wavelength response of insects to electromagnetic radiation. Greater emphasis should be placed on environmental and biological studies of soil, especially the microenvironments as they influence cycling of plant and insect pests.

Research on cultural control, management practices, and physical protection parallels and is complementary to methods of application. Success in one will assist the other, and eventually practical programs of control will utilize some of each.

CHEMICAL ATTRACTANTS, REPELLANTS AND OTHER STIMULANTS

Summary

Current research efforts are directed primarily to the control of insects, nematodes, weeds, and birds, rodents, and other vertebrates. Efforts are largely toward isolation and identification of naturally occurring stimulants, development of artificial or synthetic stimulants, techniques for using them in control operations, and mode of action.

Naturally occurring attractants for insects seem to be highly specific, and much of the research is with important species of Diptera, Lepidoptera, and to a less extent with Hymenoptera. Sex pheromones, feeding, and light attractants receive much attention. The identification of the structure of a juvenile hormone is encouraging efforts to find practical applications. Research on repellants for arthropod vectors of disease includes the search for materials that are more acceptable (particularly to military troops), long lasting, and possibly systemic. Insect-control techniques under investigation include baiting to traps or to poisons and the use of excitants and masking agents to confuse insects and thus hinder mating or feeding.

Research on attractants and repellants for the control of birds, bats, rodents, including repelling deer and rabbits from crops, and protecting birds from rodent baits is largely in the nature of empirical search for more effective chemicals and more practical methods of use.

Evaluation

Failure in the practical development and use of attractants in past years may be attributed to restrictive objectives, small-scale experiments, and undeveloped technology. Recent improvements in biological and chemical technology and new concepts in the use of attractants open up new paths for use of attractants in pest-population suppression. Sex attractants isolated, identified, and synthesized for a few major insect pests now make it possible to conduct field trials involving total insect populations in restricted or isolated areas to determine their efficacy for control or eradication. A rather similar situation exists in connection with research and development of repellants, food stimulants, and hormones. Research designed to elucidate the fundamental chemical and physical principles and the behavioral factors in mode of action is complex and often requires elaborate or highly sensitive equipment and a high degree of initiative and motivation in well-trained scientists. Developmental costs are thus high and the potential profit is low; therefore, industry cannot be expected to assume much of the cost of such research. Nevertheless, the use of such selective chemicals is in line with the key objective of making pest-control techniques highly selective with minimal contamination of the environment.

Table 10.—*Federal expenditures for research on chemical attractants, repellants, and other stimulants*

Department and agency	Scientific man-years, GS-11 and above		Funding, in thousands of dollars	
Agriculture		44.10		1,813.10
Agricultural Research Service	15.40		1,586.80	
Cooperative State Research Service	2.50		83.30	
Forest Service	3.00		140.00	
Defense		24.00		257.00
Health, Education, and Welfare		4.00		192.70
Public Health Service	4.00		192.70	
Interior		3.40		33.80
Bureau of Sport Fisheries and Wildlife	3.40		33.80	
National Science Foundation		1.40		58.00
Total		76.90		2,350.60

The availability of a rather substantial amount of Federal funds earmarked for this area of research is most apt to stimulate the efforts needed to further develop the fundamental principles of attraction and repellancy as a method of controlling pest populations. A marked increase in the rather modest funds now being expended in this category is probably justified. Especial emphasis should be given to elucidation of fundamental principles and large-scale operational testing.

INTEGRATED CONTROL

Summary

Approximately 63 percent of the current research effort in this category is aimed at developing knowledge for preventing, controlling, or eradicating parasitic diseases of ruminants, swine, poultry, and other domestic animals through studies of biological, chemical, and management methods or combined systems. The objective is to use such controls as a means of insuring economical production of meat, milk, eggs and other animal products. These studies include the following more prevalent parasitic diseases: ruminant gastrointestinal nematodiasis (species of *Cooperia, Nematodirus, Trichostrongylus, Ostertagia, Oesophagostomum, and Haemonchus*), liver flukes and bovine coccidiosis; swine kidneyworm (*Stephanurus dentatus*),

Table 15.—*Federal expenditures for research on integrated control*

Department and agency	Scientific man years (GS-11 and above)		Funding, in thousands of dollars	
Agriculture		33.66		1,912.10
Agricultural Research Service	28.70		1,775.50	
Cooperative State Research Service	4.96		136.60	
Health, Education, and Welfare		1.13		34.00
Public Health Service	1.13		34.00	
Interior		1.18		47.60
Bureau of Reclamation	1.03		43.90	
Bureau of Sport Fisheries and Wildlife	.15		3.70	
Total		34.73		1,993.70

swine nodular worm (*Oesophagostomum brevicaudum*), swine ascariasis (*Ascaris suum*), and swine strongyloidiasis (*Strongyloides ransomi*); coccidiosis in chickens and blackhead (*Histomonas*) in turkeys; equine piroplasmosis; and other miscellaneous parasitisms. Host-parasite relationship and immune response of the host to certain parasites are major areas of investigation.

A relatively small effort is directed toward more than one method of control of weed and plant diseases, flies and other insects. Here the approach is to utilize several or all known effective control methods in one system in order to reduce or avoid use of persistent insecticides.

It is apparent that considerable research effort in other sections of control methods and evaluations relate closely to integrated control. This includes research on combinations of systems involving insecticides and sterile insects, cultural-control measures and light traps, limited use of insecticides along with biological control agents and light traps with natural or synthetic chemical attractants. Research is being expanded to investigate the use of pesticides in rotation systems where a particular pest can be controlled in one crop, yet extend protection to other crops in the rotation system and often avoid residues and phytotoxicity. For example, herbicides can be applied to control crabgrass in soybeans and provide adequate control for corn in the second year. Nematocides can be used to control nematodes on corn and still protect a succeeding tobacco crop.

Evaluation

Parasite problems are becoming more critical in livestock and poultry as the latter are concentrated through modern farm practices. Increased emphasis is needed to develop biological and nonchemical methods of control of internal parasites. An expansion of current research effort will require more adequate facilities, although good progress is being made.

Integrated control holds good promise for insect control. However, few larger scale tests and specific studies have been made because such experiments are costly. Once techniques and systems are adequately tested and proven successful, private organizations may share the costs in the final testing of procedures. Plant resistance, use of pesticides, and cultural practices are a part of most research programs on pest control. An effective integrated control system would provide the basis for controlling pests on low-value crops where present control measures are too expensive or cannot be used because of phytotoxicity or residue problems. Studies specifically designed to provide integrated control of insects merit greatly expanded effort. Expanded research on integrated methods for multiple pest control is also justified.

DEVELOPMENT OF RESISTANT HOST SPECIES

Summary

A major research effort is in progress in the Department of Agriculture and the State Experiment Stations to develop pest-resistant crop plants. Limited research is performed in the Departments of the Interior and Health, Education, and Welfare. The research encompasses some phases of study related to essentially all crop commodities and to some other pests. New sources of germ plasm are sought and introduced for all kinds of crops; these are evaluated annually for resistance to crop pests, disease organisms, insects, nematodes, and parasitic weeds. Large collections of bean and other species are being evaluated for resistance to bacterial and other diseases.

Intensive research is being conducted to breed resistance to insects, nematodes, and disease organisms in new varieties of grain, oilseeds, fruits, vegetables, cotton, nuts, ornamentals, tobacco, pasture, range, and sugar crops. Considerable success has been achieved through release of (1) corn varieties resistant to the European corn borer and the corn earworm; (2) sugar cane resistant to sugar cane borer; (3) wheat resistant to Hessian fly; and (4) alfalfa resistant to aphids. Similar success has been achieved in the development of grain crops resistant to rusts and other fungal diseases, soybeans resistant to the cyst nematode,

Table 16.—*Federal expenditures for research on development of resistant host species*

Department and agency	Scientific man years (GS-11 and above)		Funding, in thousands of dollars	
Agriculture		274.55		9,138.90
Agricultural Research Service	240.70		7,826.90	
Cooperative State Research Service	29.05		777.50	
Forest Service	13.80		534.50	
Health, Education, and Welfare		1.00		43.00
Public Health Service	1.00		43.00	
Interior		0.10		1.00
Bureau of Sport Fisheries and Wildlife	0.10		0.10	
Total		275.65		9,182.90

and new potato varieties which are resistant to the golden nematode. Studies are also in progress to select pine trees for resistance to bark beetle and rust diseases.

Some attention is given to developing multiple lines of resistance in crops where several pest problems occur concurrently. The investigations also include genetic studies and determination of the mechanical, physiological, and biochemical bases for resistance of nontarget organisms to all classes of pests. Considerable Federal funds are devoted to extramural research to determine the nature of resistance of such crops as barley, corn, wheat, soybeans, alfalfa, peas, and cotton to nematodes, diseases, and insects, and the mechanism of resistance of the intermediate host for trypanosomiasis to insecticides. The research is aimed at producing crops and trees which are superior in yield, quality, uniformity, and economy of production through increased resistance to the depredations of serious pests of all major categories.

Evaluation

The development of resistant crop varieties is the most effective long-range means of combating many plant diseases, insects, and nematodes. Diseases, nematodes, and insects annually cause serious losses in agricultural production; for example, more than 200 kinds of diseases, nematodes, and insects cause serious yield and quality losses in over 50 field and forage crops; approximately 25 fruit and nut crops suffer losses due to about 150 serious pests each year; and about 150 pests reduce the annual harvest of more than 35 vegetable crops and many kinds of ornamentals. Thus, breeding for resistance to diseases, nematodes, and insects warrants continued and increased support. Meaningful gains in pest control have been attained in this area of research but have most probably only scratched the surface in reaching the full potential. The depth and breadth of exploitation of new sources of germ plasm needs to be increased to take full advantage of all sources of resistance to pests. This is particularly urgent in forage and range crops where the potential for pesticide control is minimal and in breeding for resistance to insects and diseases, the races of which become modified with time. This represents a special aspect of the general problem and needs imaginative treatment to shorten the time now required to breed resistant hosts. Breeding for multiple lines of resistance to pests, including insects, is also a primary research gap in this area. An expanded effort involving interdisciplinary teams of pathologists, entomologists, nematologists, weed scientists, and plant breeders is required. While breeding plants for resistance to weeds is impractical in most cases, the close cooperation of weed scientists is necessary to the full development of integrated pest-control systems. Such an interdisciplinary effort would assist plant breeders, for example, to develop new principles and approaches to introduce resistant germ plasm into crop varieties and to give needed attention to pests and crops now inadequately covered; that is, breeding for resistance to insects. New breeding lines and varieties need to be evaluated for resistance to pesticidal chemicals, including herbicides. The nature of resistance to crop pests and pesticides needs more intensive investigation in order to provide more efficient methods of breeding. Careful evaluation of new crop varieties requires that experiments be conducted under properly controlled conditions and refined measuring techniques used; otherwise, true differences in resistance among parental lines and in segregating populations may be obscured by environmental variability. A considerable overall increase in scientific effort is needed to fully exploit this highly desired pest-control technique.

PARASITES, PREDATORS, AND PATHOGENS

Summary

Current research efforts are directed primarily to the exploration, introduction, colonization, evaluation, distribution, and establishment of parasites, predators, and pathogens to control injurious insects, mites, nematodes, and plant diseases; introduction, evaluation, and establishment of insects and pathogens to control weeds; also introduction of fish and snails specifically to control aquatic weeds; and study of predatory animals to control birds. The scope of the research varies from fundamental studies carried out in the laboratory to evaluate the efficacy of the biological-control agents to large-scale field tests. The research is conducted at many laboratories in the United States and in foreign countries.

Insect parasites and predators are collected in different parts of the world and introduced for establishment in the United States to control or help control destructive pests, many of which originated in foreign countries. Biological control agents are being introduced, propagated, and released for control of insects affecting agricultural crops, livestock, forests, stored products, and man. Currently, research involves insect enemies of such pests as the codling moth, grasshoppers, cereal leaf beetle, bark beetles, fruit flies, alfalfa weevil, wheat stem sawfly, citrus insects, alfalfa insects, grass insects, and cotton insects. Parasites and predators are also transferred between regions of the United States. Laboratory investigations are made on life histories, breaking of diapause, rearing methods, and techniques for shipment and release of the beneficial insects.

Table 11 — *Federal expenditures for research on parasites, predators and pathogens*

Department and agency	Scientific man-years (GS-11 and above)		Funding, in thousands of dollars	
Agriculture		160.88		4,805.80
Agricultural Research Service	60.30		3,708.80	
Cooperative State Research Service	11.68		424.50	
Forest Service	5.00		172.00	
Health, Education, and Welfare		14.30		434.60
Public Health Service	14.30		434.60	
Interior		0.80		19.50
Bureau of Sport Fisheries and Wildlife	0.80		19.50	
Total		175.98		5,259.90

Many shipments of insect parasites and predators are received from Public Law 480 projects conducted in foreign countries. The insects are screened and tested and some propagated before transshipment to the United States for further study, propagation, and release.

Limited work is directed toward the use of phages to control bacteria and to discovery of nematode-trapping fungi, predaceous nematodes and other invertebrate animals that prey upon plant parasitic nematodes. Life cycles of predaceous nematodes, snails, and fish are determined as are their nutritional requirements for completion of life cycles and environmental adaptation. Limited studies are being conducted on the interaction of larval trematodes in snail hosts in hopes of eventual control of snail vectors of schistosomiasis, on *Marisa* snails as possible replacements of schistosome vectors, and searches for diseases, parasites, and predators of snails.

Aerial censuses are being made of nests and number of gull juveniles present on the maritime islands. The effects of releasing known numbers of foxes and raccoons in reducing gull breeding populations are being determined.

Studies on insect pathogens—bacteria, fungi, protozoans, nematodes, and viruses—are under way at many research laboratories in the United States. Tests are being conducted to determine their value for the control of insect and mite pests of different crops, trees, stored products, and man. Fundamental studies on insect pathogens are in progress on justification, nutrition, mode of action, and ways of reproducing the organisms. *Bacillus thuringiensis* and the DD-136 nematode are being tested against a variety of insect pests. Some new protozoans are under test against grasshoppers and mosquitoes. Insect viruses are being tested to determine their usefulness in controlling such insects as the fall armyworm, cabbage looper, grasshopper, and bollworm. Contractual research is directed toward collecting and testing foreign plant disease organisms that will attack weed species as *Ambrosia*, *Xanthia*, and *Solanum*. Work is also conducted on a *Marisa* snail, silver dollar fish, and other fish to control aquatic weeds such as elodea, milfoil, potomogeton, and hydrilla, and fish to control mosquitoes. Life cycles of snails and fish and environmental adaptation are being investigated. Surveys are under way in foreign countries to discover insect pests that might be useful in the control of introduced weeds in rangelands and aquatic environments in the United States. Insects attacking Dalmatian toadflax, alligator weed, Eurasian watermilfoil, hydrilla, water hyacinth, and Mediterranean sage are under study.

Evaluation

The chemical control of insects, nematodes, plant diseases, weeds, and birds, though effective and economical, has resulted in problems. Insects and mites have become resistant to insecticides. Intensive and extensive use of pesticides has resulted in a number of real or potential problems of residues in food and feed crops, adverse effects on fish and wildlife, and harmful effects on beneficial insects, including parasites, predators, and honey bees. Reports of the President's Science Advisory Committee and other national study groups have recommended that emphasis be given to research on the biological control of pests in order to avoid residue problems and pollution of the environment with chemical sprays.

Successful utilization of biological control agents of insects depends upon the preservation of those that already occur in natural habitats; the introduction, distribution, and establishment of additional species of parasites and predators from other parts of the world to control insect pests that have become established in the United States; and a thorough testing of the idea of mass producing the agents and releasing them on a sustained basis over a large area. The research problem area is immense if due consideration is given to the vast number of destructive insects in this country. In order to meet the needs for controlling the most important insects by this method, additional explorations must be made in foreign areas, both by scientists here and abroad conducting research possibly under the Public Law 480 program. Much additional information is required on the life history of parasites and predators, development of superior strains, nutritional needs, synchronization with hosts, development of strains resistant to insecticides, techniques for mass rearing and release, and field evaluations to determine effectiveness when introduced throughout the distributional range of an insect pest, either alone or in an integrated control program. Initial studies on biological control will have to be supported by public agencies until the utility of the method is fully demonstrated. Industry may subsequently become interested in some phases if there are opportunities for profit. The promising results obtained by using known numbers of foxes and raccoons to control gulls on islands warrants additional study. Research must be continued to determine the rate of recovery of gull breeding populations.

Some 2,000 insect pathogens—bacteria, fungi, protozoans, nematodes, and viruses—have been described. New ones are being discovered each year. Very little is known about most of these organisms in relation to the control of serious pests of agriculture, forests, stored products, and man. Basic studies on taxonomy, culture techniques, mode of action, factors that inactivate pathogens, mass production, and toxicology are needed. Protocols must be developed by regulatory agencies to determine the safety of different kinds of insect pathogens, especially viruses, if such materials are ever to become generally available as control materials. Extensive research to field test insect pathogens against a variety of insect pests is required before it can be ascertained if they are effective and can compete with chemical and other control measures.

More attention should be given to biological agents that are promising for the control of nematodes, particularly those presently requiring a heavy use of pesticides. The successful use of an introduced beetle in 1967 to control alligatorweed in Florida is an example of the great opportunities for this type of biological control. Much more effort is needed on exploration in foreign countries and introduction of insect and rust disease enemies of other weeds such as Dalmatian toadflax, Eurasian watermilfoil,

thistles, Halogeton, water hyacinth, Mediterranean sage, and wild mustards, which are now serious pests in the United States. Likewise, expanded work should be done to protect fish and snails that control aquatic weeds from herbicide-polluted water. Research on the biological control of insects, nematodes, snails, plant diseases, weeds, and birds warrants an increase in support.

TOXICOLOGY, PHYSIOLOGY, AND BEHAVIOR OF NONTARGET ORGANISMS

This problem area deals with the quantitative and qualitative aspects of toxicology. Included in this section are biological studies, exclusive of those properly classified as population dynamics and kinetics. Symptomatology (directly observable effects) of nontarget organisms, including man, animals, plants, and soil organisms, and toxicological and other physiological effects are discussed here as are research studies on the mode of action, other than that involved in control and evaluation.

SUMMARY

The most important change in toxicology during recent years has been the great emphasis on safety evaluation. Thorough testing is required as a prerequisite to registration or the granting of tolerances, and much of the work is paid for by private industry. However, the same emphasis is reflected in Federal research, especially in connection with new compounds (such as chemosterilants) or old compounds that are proposed for such specialized uses that they do not justify commercial development. Safety evaluation of new compounds or basically new uses involves measurement of toxicity and observation of symptomatology and effects on reproduction and behavior in laboratory and domestic animals, including birds, fish, and bees. These tests permit an estimate of the possible hazard of a new compound or new use to man and the creatures he values. Studies are underway on wild birds (including waterfowl, upland game birds, birds of prey, songbirds, and gulls) and wild mammals (including insectivores, herbivores, and carnivores).

Pesticides for use on crops are being studied to determine the possible harmful effects on the crops or other nontarget plants. Mechanisms of phytotoxicity are being investigated.

Laboratory evaluations of the nutrient composition and consumer-use quality of fumigated wheat and of insecticide-, nematocide-, or fungicide-treated poultry, peanuts, and selected fruits and vegetables are in progress. Basic research is being conducted on the effects of insecticides and fungicides on nutrient metabolism and requirements of rats fed different diets.

Emphasis on safety is also reflected in epidemiological studies of the possible effects of pesticides already in active use. For man, emphasis is placed on people with intensive and prolonged occupational exposure as well as those in the general population. For wildlife, emphasis is placed on populations that seem to be in special danger, whatever the reason. When poisoning does occur, the cases are observed carefully. Some progress is being made with antidotes and general therapy for man and domestic animals.

Increasing attention is being given to the biochemical and pharmacological effects of pesticides in a wide range of nontarget organisms. There is also a broadening interest in different forms of toxicity, and a number of studies are underway on the possible interaction of different toxicants.

EVALUATION

Toxicologists are agreed that the entire field deserves more emphasis and support, and all work on toxicology should take into account certain difficulties as well as numerous opportunities. The orderly development of pest control in connection with human vector-borne disease, agriculture, and wildlife management requires the careful examination of candidate pesticides and other methods of control. This examination must include orderly evaluation of safety. However, there is always a danger that this testing, no matter how detailed, will become a cookbook procedure rather than a scientific study.

Many opportunities exist to increase the usefulness of toxicology as well as the basic insight it offers. For example, toxicology is now a quantitative science. The effect of single doses have been known quantitatively for a long time; now methods are being introduced to express the effects of repeated doses numerically, and attention is being given to the dosage-response relationships of enzyme induction and various modalities of toxicity that have usually been viewed qualitatively rather than quantitatively.

Table 18.—*Federal expenditures for research in toxicology, physiology, and behavior of nontarget organisms*

Department and agency	Scientific man years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		47.73		1,668.50
Agricultural Research Service	23.60		1,132.90	
Cooperative State Research Service	10.13		331.60	
Forest Service	4.00		140.00	
Health, Education, and Welfare		87.90		3,830.60
Food and Drug Administration	22.30		1,301.00	
Public Health Service	65.30		2,529.60	
Interior		16.93		604.00
Bureau of Commercial Fisheries	5.80		230.40	
Bureau of Sport Fisheries and Wildlife	13.03		734.50	
Tennessee Valley Authority		0.30		13.00
Total		154.96		6,417.00

It should be recognized that quantitative studies of wild species offer special difficulty because, by necessity, these studies are confined to species that can be reared rather easily. There is a possibility that studies of wild forms may be biased in favor of tough, resilient species. Work needs to be done to explore more fully the diversity of species response and the reasons for it.

New developments in biochemistry and other aspects of molecular biology offer great opportunities in toxicology. However, these developments often must be related carefully to the entire organism and evaluated in terms of their relevance to the health of the intact nontarget species. Each development of a nonchemical method of pest control offers a challenge to develop meaningful techniques for measuring its safety. An expert committee of the World Health Organization has stated "Any material — living or dead — which it is proposed to introduce as a pest control agent should be subjected to the same searching examination for potential toxicity to man as is applied to the synthetic pesticides."

PESTICIDE KINETICS

ABSORPTION, DISTRIBUTION, CHEMICAL METABOLISM, ACCUMULATION AND EXCRETION

Ecosystem studies measure the distribution of pesticides through the various parts of the flora and fauna and the transfer and accumulation of pesticides through the food-chain mechanism. Changes in pesticides by chemical metabolism and losses by air and fort water transport can be measured. Studies of individual organisms measure the process of absorption, distribution, chemical metabolism, accumulation, and excretion. Both target and nontarget organisms are included in these studies.

Summary

Investigations of pesticide kinetics are directed toward an understanding of the impact of pesticides on man and the ecological system upon which he depends. Research strategy includes a simultaneous attack on problems of pesticide kinetics in the ecosystem and in the organisms; thus, studies of the distribution and changes of pesticides

Table 19. — *Federal expenditures in research on pesticide kinetics*

Subcategory	Scientific man years, GS–11 and above	Funding, in thousands of dollars
Absorption, distribution, chemical metabolism, accumulation, and excretion	598.7a	10,985.15
Methods of speeding residue loss	17.98	[illegible] 678.30
Stability of pesticides in storage	4.15	114.90
Total	630.89	11,778.35

Table 20. — *Federal expenditures for research on absorption, distribution, chemical metabolism, accumulation, and excretion*

Department and agency	Scientific man years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		140.5a		6,114.40
Agricultural Research Service	88.60		4,365.70	
Cooperative State Research Service	57.90		1,748.70	
Health, Education, and Welfare		413.00		3,859.35
Food and Drug Administration	1.00		32.00	
Public Health Service	414.00		3,827.35	
Interior		34.65		710.40
Bureau of Commercial Fisheries	7.10		282.80	
Bureau of Sport Fisheries and Wildlife	11.55		198.00	
Federal Water Pollution Control Administration	14.00		123.60	
Geological Survey	2.00		44.00	
Atomic Energy Commission		2.50		61.00
Total		590.7a		10,985.15

in living and nonliving parts of the environment are paralleled by studies of absorption, metabolism accumulation, and excretion of pesticides in man, wild and domestic animals, and plants. Significance of pesticides to the health of man and domestic animals or to wild populations cannot be adequately appraised from observational and descriptive studies under the complex and uncontrolled conditions existing in the environment. Although studies of pesticide interrelationships of plants, water, or soil can be conducted under practical conditions, they too require much supplemental study in controlled laboratory experiment.

Studies are being conducted of both target and nontarget organisms in relation to the kinetics of all major classes of pesticidal chemicals. Research thus includes studies of man, laboratory and domestic birds, mammals, plants, and wild species of birds, mammals, fish, and the invertebrates they feed upon.

Residues in crop plants, soils, and water and their interrelationships receive the major emphasis, in that order, and these three areas receive more than half the research dollars. Residues that result from treatment programs receive particular attention; studies include research on metabolic changes of pesticidal chemicals due to soil organisms and other causes and persistence and effects of residues in soils, plants, and water and the exchange between them. Additional studies pertain to residues in meat, milk, and eggs. These entail studies of the absorption, metabolism, storage, and excretion of pesticides by domesticated mammals and, to a lesser extent, domesticated birds.

Pesticide kinetics in the human food chain thus is the primary focus of research effort. Kinetic processes in man

are studied through experimental research with appropriate laboratory animals and by some studies with man himself.

Residues in water and their transport and changes are studied in relation both to crop production and to the drinking water supply, which includes underground waters. The primary objective of the few studies underway concerning the air transport of pesticides is the determination of drift from treatments.

Some ecological studies of pesticides and the parallel experimental investigations required for interpretation are being made in relation to wild species of fish, shellfish, food-chain organisms in the fresh water and marine environments, and birds, mammals and food organisms in the terrestrial environment.

Evaluation

The large number of new chemicals, the persistence of old ones, and the use of chemicals in a variety of combinations and solvent systems have overwhelmed the research effort aimed at understanding their distribution and effects. Use of pesticides of all classes increases each year, and there is little knowledge of their interactions and impact upon the ecological system. Man has added many toxic chemicals to the environment in addition to those derived from pesticides, a further complication. Ecological effects of pesticides must be evaluated in the context of total environmental pollution.

The significance of residues is poorly understood, and studies aimed at this understanding are the primary research need. A great effort in experimental and interpretive studies must be made to capitalize upon the first-step descriptive effort that has predominated in past work and to permit proper evaluation of ecological problems. It is therefore essential to learn the rates and routes of transport of chemicals in the air and water and in terrestrial and aquatic organisms, the extent and the mechanisms of degradation, and the degree of accumulation in terrestrial and aquatic food chains. Controlled ecological studies in the field or in microecosystems are seriously needed.

It is equally essential to greatly increase research on the kinetics of pesticides in organisms, both plants and animals, in order to encompass more species and to seek relationships between residues and effects on behavior, reproduction, enzyme activity, stresses of various kinds, and interactions. Long-term low-dosage studies, including studies of progeny are particularly necessary. The animal species should include representatives of all major groups of vertebrates and invertebrates—man, laboratory and domestic mammals and birds, wild species of birds, fish, and mammals, and selections from other groups.

METHODS OF SPEEDING RESIDUE LOSS

Summary

Research is concentrated in several specific areas that include methods of decontaminating soil, water, and plants

Table 11.—*Federal expenditures for research on methods of speeding residue loss*

Department and agency	Scientific man years, FY 71 and above		Funding, in thousands of dollars	
Agriculture		10.10		420.00
Agriculture Research Service	6.40		334.00	
Cooperative State Research Service	3.90		166.30	
Health, Education, and Welfare		8.10		93.00
Public Health Service	8.10		93.00	
Interior		3.50		166.00
Bureau of Commercial Fisheries	3.00		115.00	
Bureau of Sport Fisheries and Wildlife	.50		51.00	
Total		17.90		679.30

which contain pesticide residues. Decontamination may be accomplished by several means such as application of certain microorganisms, chemicals, or adsorbants. The use of ultraviolet irradiation is also under investigation.

Since pesticide residues existing in used containers or other sources of unused pesticides may contribute to contamination of the environment, more effective means are being sought to improve disposal procedures. Research is underway to develop more effective incineration including possible pretreatment of pesticides before incineration. Research on design of more suitable containers is being sought from the container industry.

The effect of processing of foods on the rate of loss of pesticide residues is under investigation. Information on the effects of home and commercial preparations on residue levels in foods is being obtained. In the area of decreasing residue levels of animals used for food, research into methods of storing and preserving forage is being conducted to see if the final amount of pesticide residue in the animal can be lowered before it is processed for food.

A small effort is in process to study the prevention of pesticide migration through containers treated to repel or kill insects. Various formulations and container surfaces are being investigated. This project is one involving cooperation with the paper, container, and chemical industries.

The removal of pesticides from the atmosphere (air) is necessary where spraying and formulation processes have been carried out. Pesticide vapors, toxic dusts, and mists constitute a definite hazard to workers. Research into respiratory protective devices is necessary and is being supported by some government agencies. The new chemicals being produced each year as pesticides require testing to insure safety when working with them as sprays or other applications.

Evaluation

Since pesticide residue levels have been shown to exist throughout various materials in our environment, a greatly increased research effort should be undertaken in the area of direct decontamination of soils, water, plants, and plant and animal food products which are known to contain significant residue levels. In addition, research into management techniques which will decrease the residue level of persistent pesticides in animals (both wildlife and domestic food animals) should continue to be investigated. Laboratory studies have provided some good results in application of techniques such as use of microorganisms to decrease pesticide levels in soil. Research results on these techniques as applied to field conditions are greatly needed.

The major stimulus towards increased research on decontamination of pesticide containers and removal of unused pesticides has come from vastly increased usage of these materials. Research into incineration techniques, pretreatment, and ultimate disposal of the final waste product (hopefully nontoxic) must be greatly increased. There should be a greater emphasis on cooperation with private industry in the area of container research. There have been suggestions that in the future, industry, as part of the registration of pesticides, should be required to provide data on ultimate disposal requirements. The registration data might also provide information on suitable microbial or chemical detoxification agents so as to ensure nonpersistent, nontoxic residue.

Continuing effort will be required to remove pesticide vapors or dusts from the air. This is primarily due to the introduction of new chemicals each year. Practical methods also need to be developed to remove herbicides and other pesticides from water after intentional and unintentional contamination.

STABILITY OF PESTICIDES IN STORAGE

Summary

Current research efforts are directed toward the development of information about the stability of pesticides in storage under varying climatological conditions and their degradation and formation of toxic by-products. Research ranges from the most basic — analysis of the chemical and gaseous components of incinerated pesticides — to the more general — biological testing of effects of long-range storage on the toxicity of a given pesticide.

Considerable effort is being directed toward the problem of storage stability of wettable powders and emulsifiable concentrates used in worldwide vector control and eradication programs. Additional effort has been directed toward the factors involved in the decomposition of pesticides stored under a variety of conditions of temperature, moisture, pressure, light, and other considerations. A limited amount of research, mostly exploratory in nature, is being conducted in an effort to develop equipment for the decontamination and disposal of pesticides and pesticide containers. The stability of pesticides to lye and other alkalies, mineral acids, and strong oxidizing and reducing agents are also being investigated.

Table 11 — *Federal expenditures for research on stability of pesticides in storage*

Department and agency	Scientific man-years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		1.40		54.0
Agricultural Research Service	1.40		54.0	
Health, Education, and Welfare		0.75		30.0
Public Health Service	0.75		30.0	
Interior		3.00		30.0
Geological Survey	3.00		30.0	
Total		5.15		114.0

Basic studies are being conducted to determine the extent and probability of future contamination of water resources in selected areas resulting from land disposal of pesticides and pesticide containers.

Evaluation

Considerable progress has been made in recent years to develop methods of stabilizing pesticides in storage. However, due to additional pest species becoming resistant to pesticides and the resultant need for more toxic and selective pesticides, the long transit and storage time associated with worldwide eradication and vector-control programs in progress, and environmental contamination caused by pesticides and pesticide containers, new and perplexing problems have been created which will require investigation. Public concern over these problems is becoming increasingly and justifiably more evident.

There is a need for continued research on the stability of pesticides in storage; this effort should be expanded to include the design of better, more durable, and safer pesticide containers that would withstand the stress of transit and could be disposed of with a minimum of hazard to the environment. These problems seem to be recognized and rather well defined, but increased effort and coordination will have to be made by the agencies concerned, both Federal and non-Federal.

DEVELOPMENT AND STANDARDIZATION OF ANALYTICAL METHODS

SUMMARY

Primary emphasis is being directed toward two basic areas — methods for determining pesticide residues in food and food components of both plant and animal origin and methods for determining pesticide residues in human organs and tissues. Research is also being supported to a lesser degree to determine residues in environmental items such as water, soils, air, insects, and wildlife.

Table 11.—*Federal expenditures for research on development and standardization of analytical methods*

Department and agency	Scientific man years, GS-11 and above		Funding, in thousands of dollars	
Agriculture		17.89		640.90
Agricultural Research Service	13.40		543.90	
Cooperative State Research Service	4.49		97.10	
Health, Education, and Welfare		57.95		3,814.00
Food and Drug Administration	22.00		753.00	
Public Health Service	35.95		3,061.00	
Interior		15.25		640.50
Bureau of Sport Fisheries and Wildlife	5.25		189.00	
Federal Water Pollution Control Administration	5.00		97.50	
Geological Survey	5.00		60.00	
Total		91.09		3,095.40

Major efforts in new methodology for food and feed components are in organophosphates and to a lesser extent carbamates. The very labile nature of these pesticides (as compared with the organochlorides) especially requires a thorough understanding of the nature of all possible resulting residue components. Research is directed toward the effectiveness of various extraction procedures and the analytical behavior so that the detection of a greater number of these pesticides and their alteration products can be included into one procedure with a high degree of sensitivity. A substantial research effort is also being devoted to the development of analytical methods for various types of herbicides and fungicides.

Recently efforts have been intensified for the identification of alteration products of the chloro-organics. These efforts have uncovered many previously unknown residue components which may need to be incorporated (depending on their toxicities) into identification procedures.

In the area of pesticide residues in humans, emphasis is being placed on developing new and improved techniques to determine pesticides in human liver, brain, kidney tissue, urine, blood, and fat by establishing a central analytical laboratory which will contain the most up-to-date instrumentation and techniques. Studies are being conducted on the effect of existing preservation methods of tissues upon recovery of pesticide residue and by continuous monitoring and storing of samples taken from humans exposed to various amounts of pesticides. A complete tissue bank is being established to monitor existing conditions and to develop knowledge on the effect of pesticide residues on humans.

About half as much effort as is being devoted to research on pesticide residues in food is going into the development, standardization, and improvement of methods for detection and quantification of pesticides (especially organophosphates) and their alteration products in water and the biologically active mud-water interface. The major problem in obtaining a representative sample of the mud-water interface is that of disturbing the interface when taking the sample.

The effort being directed to improve methodology for determination of pesticidal residues in wildlife, insects, plants and their environments is about as much as one-half the support for pesticides in water. Emphasis is being placed on determination of pesticides and their metabolites in insects, plants, and fish and bird eggs plus blood, fat and other tissues.

Considerably less research is being devoted to development of methods for many quantities of pesticides, surfactants, and carriers used in vector control and (or) eradication programs necessary for developing new and improving existing specifications for application and formulation. A substantial amount of the effort devoted to standardization and validation of analytical methods for pesticide formulations and residues in foods is conducted under the coordination of the Association of Official Analytical Chemists (AOAC), an organization whose active members consist of Federal and State scientists who cooperate with associate members from industry and other institutions. Methods validated under the auspices of this organization are generally accepted as valid in legal actions brought by the Food and Drug Administration and the Department of Agriculture. These methods are also used by the Food and Drug Administration in their monitoring and surveillance programs.

EVALUATION

The problem of recommending all necessary adjustments in government-supported research for this problem area is difficult with the information made available to us. The following recommendations should, therefore, be considered as examples of needed research and not a definitive evaluation.

The effort devoted to the problem of pesticide residues in food and food components needs much intensification to identify the analytical characteristics of all pesticides and their alteration products so that residues can be determined with the minimum number of procedures and the required sensitivity. Research emphasis in analytical methods must be correlated with changing pesticide use patterns. Research is specifically needed in methodology for the organophosphates and carbamates and their alteration products and multiple-detection methodology is also needed for the diverse types of herbicides and fungicides. Methods sensitive and specific enough to be used for measuring residues in the total diet are necessary to accurately define the effect of these chemicals on the human, plant, and animal environment. A moderate increase should yield sufficient information to significantly define these effects.

One of the specific programs that should be intensified is the investigation of simplified, rapid, economical, and

precise field measurement techniques, particularly for water analysis, in order to better obtain correct information for evaluation. Emphasis should be increased to develop methods for measuring residues in fish and other aquatic fauna and in aquatic soils.

The study of the problem of losses of pesticides at various stages in the analysis of plant and animal tissues and eggs making use of 14C-labeled organochlorine insecticides and the effect of the various preservation methods of tissues upon the recovery of pesticide residues should be greatly increased. In addition, research should be initiated for the isolation and positive identification of unknown chromatographic peaks commonly encountered in the analysis of wildlife and fish specimens and the development of analytical methods for unregistered chemicals used in fisheries.

MARKETING, UTILIZATION, SOCIOLOGY, AND LAW

SUMMARY

Current research efforts are directed primarily toward the marketing and utilization of pesticides. The market acceptance of tobacco, seeds, and food products is being studied by determining market values of these products after various pesticides have been used during the growth and processing stages. The economic impact on farmers of changes in tolerance levels of pesticide residues in food products and of required disuse periods of land declared to be contaminated is under limited study. Numerous studies deal with formulations for the effective use of pesticides and improved methods of application but few are investigating the sources and adequacy of pesticide information available to bulk dealers of pesticides, the extent to which dealers understand and are able to convey pesticide information to consumers, and finally the degree of consumer compliance with verbal or printed instruction.

The sociological aspects of pesticide use are being investigated by studies of (1) consumer awareness of the use of pesticides and their understanding of the pesticide problems, (2) impact of consumer attitude toward the use of pesticides on the food purchase and consumption pattern of the family, and (3) relationships between awareness of the pesticide problem, attitude toward the problem, its effect on food use and consumer characteristics which are indicative of their socioeconomic and educational levels. Some evaluation of the economic impact of alternative methods of pest control both for representative farms in selected areas and for agriculture as a whole is in progress. No studies on the legal aspects of pesticide use were found which could be identified as research. Legal activities consist of the review and evaluation of applications for registration and of pesticide petitions only.

Table 14.—*Federal expenditures for research on marketing, utilization, sociology, and law*

Department and agency	Scientific man-years, GS–11 and above		Funding, in thousands of dollars	
Agriculture		6.70		156.40
Cooperative State Research Service	6.70		156.40	
Defense		1.00		61.00
Health, Education, and Welfare				
Public Health Service	0.25	.10	10.00	10.00
Total		11.95		227.40

EVALUATION

Research in these areas has been very meager because there has been a general lack of awareness of the dangers associated with the use of pesticides. Now that the scientific community is acutely aware of the dangers of pesticidal pollution of the environment, strong efforts should be made to assess the adequacy of pesticide information available to dealers and their capability to convey this information to consumers. Of course, such efforts should be followed by a suitable educational program.

Another area which should receive increased attention is the economics of alternative methods of pest control. The results should be of great interest to the pesticide industry as well as planners of pest control research programs. In view of the paucity of information on the cost-effectiveness of alternative pest control methods, support of this work should be greatly increased.

Required research in the legal aspects of pesticide use is difficult to identify. Therefore, a small level of support for exploratory studies is recommended. This area may well attain major importance if aerial dissemination of pesticides becomes widespread, particularly if applied at State and national boundaries.

The current level of activity in the sociological aspects of pesticide use is probably adequate, except as it relates to public acceptance of recommendations for safe and effective use.

DISCUSSION

The first step in evaluating the adequacy of federally financed research on pests and their control is to select a systematic arrangement for the analysis. The one chosen was selected because of the committee's belief that it would give the best overview of the subject. On the other hand, it is not a convenient arrangement for evaluating the relative emphasis being given, for instance, to insects versus weeds or rats versus plant viruses. Therefore, this type of comparison cannot be derived from this analysis.

Table 1 shows that there is a wide range of effort being expended in the various subcategories of this classification system. This does not imply that those with the least support are necessarily those in most urgent need of strengthening, for the classification was not designed to provide all subcategories of equal importance. Nevertheless, it is

immediately apparent that evaluation of need for control and marketing, utilization, sociology, and legal receive very little research support at present, and both of these should justify considerable intensification of effort. In fact, a detailed evaluation of each subcategory in all problem areas indicates specific needs for strengthening research support in each.

Also the fact that several agencies may be supporting research in the same subcategory usually represents research with similar objectives but directed against different pests. The committee found some areas of apparent duplication between agencies, but it learned that this was generally planned as a desirable check on applicability of results to different situations. To provide a more balanced evaluation, the committee decided to indicate areas of most urgent need without regard for exactly where these needs fit into the classification system. Hence the following recommendations cut across many of the research categories.

1. Ecological significance of pest control.

The most urgent need appears to be for a more comprehensive understanding of the ecological significance of the control of pests. Currently there is great public interest in the challenge that massive environmental contamination offers to man's welfare. Because pesticides are biologically active they may have ecological significance out of proportion to their concentration as compared with other kinds of pollutants. Persistent pesticides are especially feared because harmful effects may not be discovered until too late to correct the contamination. Research is urgently needed to more adequately evaluate these possibilities.

a. A thorough evaluation of the problem will require more information than is now available on the fate of each pesticide in the environment. A knowledge of the identity of alteration products and of the concentration of residues in soil, water, air, and the biota is the first requirement. This is being acquired through national monitoring programs coordinated by the Federal Committee on Pest Control. Detailed information is also needed on how rapidly and by what mechanisms each pesticide is degraded chemically or biologically in these various elements of the environment and how freely it moves from one to another or is translocated by plants or other organisms.

b. Detailed information is needed on the toxicity of pesticides to the many different organisms which may be exposed in soil, water, or air or through their foods. Because of the complex nature of the biota in any particular situation it will doubtless require long-term studies of the biological populations as a whole rather than being limited to a few indicator species. The interactions between various pesticides and of each with other contaminants must be included because of the fact that one toxicant may increase or decrease susceptibility to others.

c. Much of the present effort along these lines is limited to persistent pesticides and particularly to chlorinated hydrocarbons. It is recognized, however, that some of the less persistent and more specific pesticides may also cause severe ecological damage. Thus some of the carbamate insecticides which are relatively transient are nevertheless very toxic to bees, and repeated applications could have important ecological effects by interfering with pollination. Likewise, nonchemical control methods such as burning to control insects and plant disease or oil clearing out hedgerows to control weeds or even water level management to control mosquitoes may have significant ecological effects. Therefore, studies of long-term ecological effects should include all widely used pesticides and nonchemical control procedures as well as the chlorinated hydrocarbons.

2. Additional toxicological research.

Though there has been much toxicological research on pesticides in recent years, some aspects need more attention. Emphasis should be on physiological, behavioral, and other sublethal effects. These should include studies of both plants and animals.

a. The physiological effects of pesticides on plants are poorly understood except for the direct toxicity of herbicides. More should be done on less obvious physiological effects of all pesticides particularly as they may affect nutrition, taste, and similar characteristics of the plant as human food. This should include the effects of metabolites in the plants, and interactions between pesticides and plant growth.

b. The physiological effects of pesticides on insects, fish, and wild and domestic species of birds and mammals have received remarkably little study, and such studies are seriously needed for a proper long-term evaluation.

c. The search for possible subtle effects of long continued exposure to pesticides by humans should be continued on a permanent basis among the population most heavily exposed. In the long run this is the best safeguard that we have against unexpected effects following long-term exposures of the general public—a fear that occurs widely and can not be reassured adequately by any other method.

3. Protection of environment from contamination by pesticides.

It is generally assumed that contamination of the environment by pesticides is undesirable. Therefore research on methods of reducing or preventing contamination and of removing unavoidable residues is urgently needed.

a. Probably the single most important source of needless contamination is inefficient application of pesticides. Improved equipment and application techniques are highly desirable. Developments in this field have been generally the result of applied research; any significant further improvements will depend upon more fundamental knowledge coupled with a high degree of initiative and ingenuity in devising new and radically different methods of application.

b. Contamination from wastes such as surplus mixes, residues in "empty" containers, or no spillage, and so forth is probably less in total quantity than that from inefficient application; it may be of even greater significance because of the much higher concentrations involved. Almost nothing is known at present about economically feasible and

practical methods of destroying waste pesticides. Incineration, deep-well disposal, and controlled surface burial are all probably technologically feasible in locations where quantities justify sophisticated techniques, but additional developmental research is needed to make them practicable. Much more initiative and ingenuity is needed on acceptable methods of disposal for use in local areas with relatively small volumes of waste. Concurrent development of packaging methods that would reduce or eliminate such wastes is also urgently needed. A third alternative is a practical method of decontaminating containers and spillage.

c. Additional research on methods for removing residues from soil, water, and air could have a major effect on protecting the environment. Most current research along these lines deals with protection of food crops from residues in soil, of milk from residues in cattle, or of humans from residues in air or water. Information on how residues could be detoxified or removed from soil on a massive scale could be important in the future.

4. Reduction in overall use of chemical pesticides.

Historically, use of biological and cultural methods of pest control commanded as much or more research effort than chemical methods. The development of important new chemicals during and immediately after World War II resulted in an overwhelming reliance upon chemical pesticides. Within only the past few years, development of pests resistant to chemicals and an increasing awareness of other undesirable side effects has resulted in renewed interests in nonchemical techniques and concurrently in greatly increased regulatory restrictions on chemical pesticides. In fact the economic consequences of the restrictions and the public pressure to reduce contamination have sharply reduced the development of new chemical pesticides. This, coupled with the desire to reduce contamination of the environment, means that even greater efforts must be devoted to research on nonchemical methods of control of pests.

a. A number of new techniques of control need further development. Perhaps the best publicized of these is the sterilization of insects using either radiation or chemicals. This, like various biological control methods, involves mass rearing techniques and release over a wide area; therefore they are not practical for individual users. Full exploitation of these techniques will require expensive development of large-scale production methods and a system of application to large geographical areas as a unit.

b. Integration of a variety of control techniques into pest population management is probably the most significant pest-control challenge today to collaboration between all elements of the research community concerned. Currently control of pests is directed chiefly at reducing populations as low as is economically feasible. There is growing evidence that many pest populations can be more efficiently managed with less ecological disturbance by selecting a somewhat higher population level but one at which the pest damage is acceptable. The determination of this level will vary with each situation. It must be developed through the collaboration of social scientists as well as biologists. Similarly the proper balance between the various methods of control can be determined only by collaborative efforts of a variety of specialists.

The development of such integrated control systems involving all pests in a given area as well as all useful control methods probably offers the best solution to reduction of cost and hazard to man and the environment from damage caused by the pests.

5. Need for control.

An essential part of an integrated program of scientific pest-population management is a determination of the population level at which pest damage is acceptable, or conversely at what level further control is necessary. It is perhaps significant that over 90 percent of the Federal effort reported for research on evaluation of need for control deals with health aspects. Much more research of a planned and objective nature is needed, not only to guide integrated population management efforts but to justify the specific pests against which all types of control research is directed.

6. Public understanding of pest-control policies.

It is not sufficient that scientists know that the use of a pesticide in the control of a particular pest is in the best public interest. An informed public is needed to accept the cost of such efforts and the hazards to the environment that may be justified. Moreover, a significant part of the protection of the environment as well as individuals depends upon the safe and proper use of pesticides and disposal of wastes by the individual user. Few legal controls on actual use are either practical or desirable; rather major emphasis is properly placed on educational efforts. Yet practically no Federal research effort has been devoted to learning how the user gets his information and how he can be influenced to accept good practices. Urgently needed is sociological research to provide a guide not only to educational efforts but to effective methods of regulating, marketing, and utilization of pesticides.

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